

Journal of Applied Remote Sensing

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Binyam Tesfaw Hailu, Mekbib Fekadu, Thomas Nauss, "Availability of global and national scale land cover products and their accuracy in mountainous areas of Ethiopia: a review," *J. Appl. Remote Sens.* **12**(4), 041502 (2018), doi: 10.1117/1.JRS.12.041502.

Availability of global and national scale land cover products and their accuracy in mountainous areas of Ethiopia: a review

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Abstract. A large variety of remote sensing-based land use/land cover (LULC) products are currently available on national and global scales. This literature review and *in situ* validation study evaluate the suitability of these products for local scale applications in the complex terrain of the Ethiopian mountains. For the review, 146 research papers are analyzed. Most studies (73%) have been published since 2013 and are based on individually computed maps. Not a single study relied on readily available LULC products. Nine readily available LULC products with 20-, 30-, 300-, 500-, and 1000-m spatial resolution have been identified at national and global scales. To complement and extend this body of research, the recent (since 2013) LULC products are validated using 185 ground truth points collected in the Bale Mountains National Park between 1500 and 4385 m a.s.l. The results indicate a rather poor overall accuracy (<50%). © The Authors. Published by SPIE under a Creative Commons Attribution 3.0 Unported License. Distribution or reproduction of this work in whole or in part requires full attribution of the original publication, including its DOI. [DOI: [10.1117/1.JRS.12.041502](https://doi.org/10.1117/1.JRS.12.041502)]

Keywords: land use/land cover products; systematic review; Bale Mountains National Park; Ethiopia.

Paper 180667V received Aug. 9, 2018; accepted for publication Nov. 27, 2018; published online Dec. 21, 2018.

1 Introduction

Land use/land cover (LULC) information is heavily utilized for mapping environmental conditions and monitoring changes such as deforestation, land degradation, drought, or urbanization.^{1,2} LULC change is a major driver of biodiversity loss and affects climate change response, ecosystem structure and functioning, water and energy balance, and agroecological potential.³ Adequate information on LULC is, therefore, required on global, national, and local scales.

In Ethiopia, deforestation is one of the major processes of LULC change. Fuel wood collection, timber extraction, commercial agriculture, and charcoal production are the primary direct drivers. Indirect drivers are population growth, essential for commodities, governance, and economic growth.⁴⁻⁷ LULC change is also a major challenge with a strong impact on the agricultural development process and the implementation of the country's main development strategies, such as the growth and transformation plan developed by Ministry of Finance and Economic Development and the 2011 climate-resilient green economy strategy.⁸

Remote sensing provides complete, area-wide observations of LULC at a variety of temporal and spatial scales. Many studies describe the potential of satellite sensors and analysis techniques to retrieve environmental variables and monitor biological and physical processes relevant to global change research. For example, researchers use such data for forest resources studies,⁹ vegetation mapping,¹⁰ forest health studies in terms of cost effectiveness and resolution,¹¹

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land degradation assessment,¹² crop production forecast,¹³ urban planning and management,¹⁴ climate change studies,¹⁵ road extraction,¹⁶ and meteorology applications.¹⁷

Although researchers, organizations, and individuals produce LULC maps at global to regional scales for many applications, the accuracy of these products in high-altitude areas and their utilization for local scale applications is still unknown. Therefore, this research aims to identify the available LULC products, review literatures regarding usage of LULC products in Ethiopia, and evaluate accuracy of these products at a local scale (high-altitude range area) using systematic review and meta-analysis methods, respectively.

2 Study Area, Source of Data, and Methods

The study area is in the Bale Mountains National Park (BMNP) within the Eastern Afromontane Biodiversity Hotspot (EABH).^{18,19} The area stretches from 39.47° to 39.95° E and 6.49° to 7.15° N and spans an elevation range between 1500 and 4385 m a.s.l. (Fig. 1).

2.1 Literature Review

For the literature review, we systematically collected 146 studies focusing on LULC mapping and its use in Ethiopia. The studies were all published in peer-reviewed journals between 2000 and 2018. We followed the systematic review approach by Cook et al.²⁰ and used descriptive statistics to synthesize the results. First, we clearly formulated the question: “Do researchers utilize existing LULC products in Ethiopia?” Second, we defined inclusion and exclusion criteria for retrieving literature from the Google Scholar search engine. The set was based on (i) the year of publication and (ii) the geographic location, i.e., “2000 < ‘publication year’ < 2018 and geographic location = ‘Ethiopia’”. This returned 146 studies. Third, the literature was synthesized based on study location, elevation range, use of satellite images and LULC products, publication year, and accuracy assessment results. Finally, quantitative data synthesis was applied to elucidate whether the literature used readily available national to global scale LULC products.

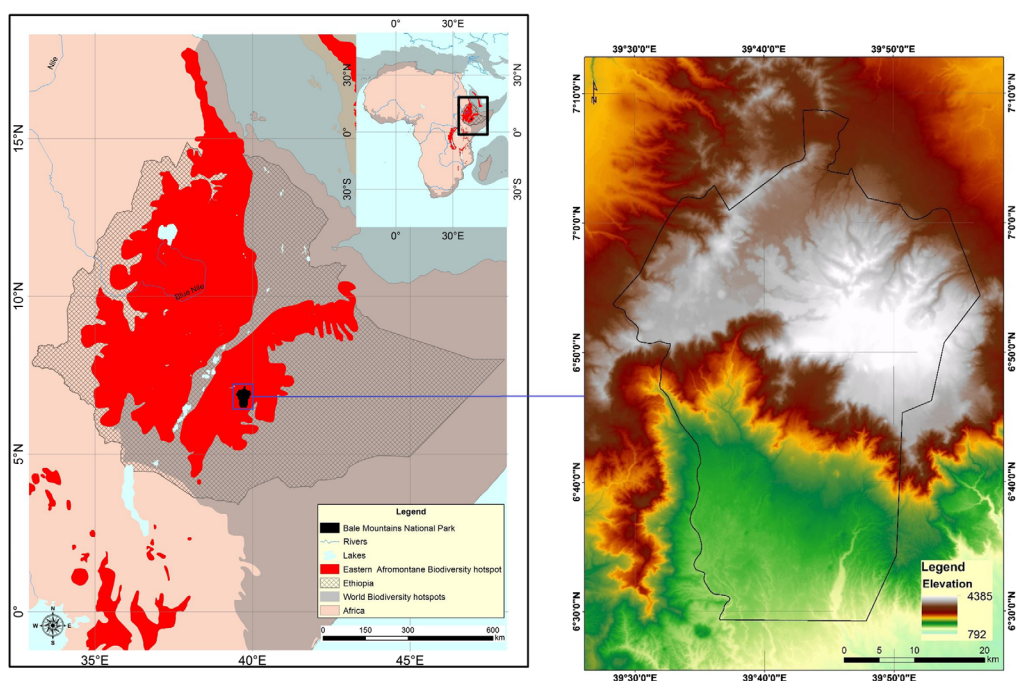


Fig. 1 BMNP within the EABH and its elevation profile from the Shuttle Radar Topographic Mission (SRTM) 30-m digital elevation model.

2.2 National to Global Scale LULC Products Used within the Reviewed Literature

Many LULC products were used in the 146 reviewed studies. Of these, only nine were readily available on a national to global scale. These are the Moderate Resolution Imaging Spectroradiometer (MODIS) land cover, the Global Land Cover 2000, 2005, and 2009 (GlobCover V2.2 and 2.3), the Ethiopian Land Cover Maps by the Regional Center for Mapping of Resources for Development (RCMRD) and the Ethiopian Mapping Agency (EMA) the GlobeLand30, the Global Land Cover by the National Mapping Organization (GLCNMO), the UN Food and Agriculture Organization (FAO) Global Land Cover Network (GLC-SHARE), the Africa Land Cover Maps (ALCM) by Midekisa et al.,¹ and the Climate Change Initiatives Land Cover Africa (CCILCA).

The MODIS land cover product has five types (types 1 to 5) of classification schemes that retrieve land cover properties based on 1 year of observations by Terra and Aqua MODIS. In this paper, the International Geosphere Biosphere Program (IGBP) global vegetation classification scheme (GVCS) with 17 land cover classes was used (MODIS land cover product version 051).¹⁸

The Global Land Cover 2000 product is produced from 1-km Satellite Pour l'Observation de la Terre (SPOT4) observations acquired between November 1999 and December 2000.^{21,22} The product uses the United Nation Land Cover Classification System (UN-LCCS) after unsupervised classification (ISODATA)²³ and contains two levels of land cover information: a detailed level with 44 land cover classes for each continent²⁴ and a harmonized level with 22 regional classes.²¹

The Global Land Cover 2005 product (GlobCover V2.2) was derived by regionally tuned and automatically classified Medium-Spectral Resolution Imaging Spectrometer (MERIS, Envisat satellite system) observations between December 2004 and June 2006.²⁵ Again, the UN-LCCS is used as the classification system. For the Global Land Cover 2009 (GlobCover V2.3), MERIS observations between January 2009 and December 2009 were used.^{26,27}

The RCMRD and EMA LULC products are produced from 39 Landsat TM and enhanced thematic mapper (ETM) images from 2003, 2008, and 2013 as part of the “Land Cover Mapping for the Development of Green House Gas Inventories in East and Southern Africa” project by RCMRD and NASA SERVIR-Eastern and Southern Africa. The observations were acquired

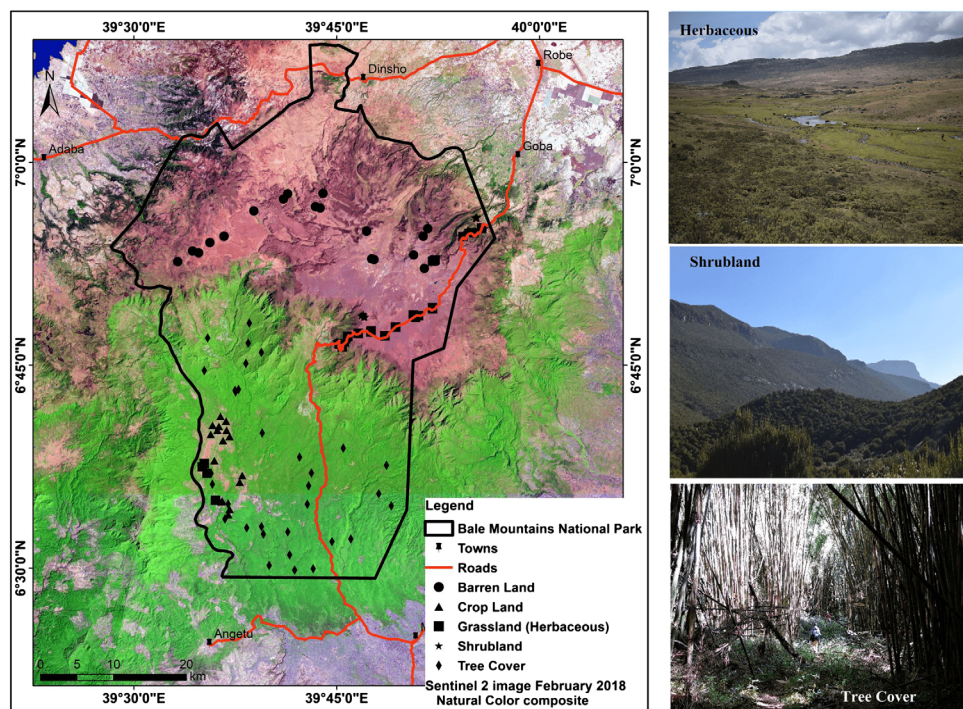


Fig. 2 Map showing the distribution of ground truth points in BMNP.

from the USGS website and preprocessed by RCMRD-SERVIR Africa.²⁸ In the case of Ethiopia, the project was coordinated through the government-appointed national greenhouse gases team led by the EMA.

The GlobeLand30 LULC product provided by China maps global land cover at 30-m spatial resolution.^{29,30} It uses a pixel-object-knowledge-based operational approach with two steps in the determination of land feature classes. First, the classification of 10 land cover classes is decomposed into simpler per-class classifications in a prioritized sequence and second, the per-class classification results are merged together. A knowledge-based interactive verification step is integrated to improve the quality of data product.

Table 1 User-defined LULC class descriptions based on UN-LCCS and IGBP-GVCS.

User-defined classes	Description (UN-LCCS)	Description (IGBP-GVCS)
Trees	Tree cover, broadleaved, evergreen; >15% tree cover; closed >40% tree cover; open 15% to 40% tree cover; deciduous, needle-leaved, evergreen; mixed leaf type	Evergreen needleleaf, broadleaf forest; deciduous needleleaf forest; mixed forest
Grassland (herbaceous)	Herbaceous cover, closed-open (i) natural, (ii) pasture; sparse herbaceous; regularly flooded herbaceous cover	Grasslands and wetlands
Shrubland	Shrub cover, closed-open, evergreen (sparse tree layer); shrub cover, closed-open, deciduous (sparse tree layer)	Closed and open shrublands
Cropland	Cultivated and managed areas (i) terrestrial; (ii) aquatic (flooded during cultivation), and under terrestrial; (iii) tree crop and shrubs (perennial); (iv) herbaceous crops (annual), nonirrigated; and (v) herbaceous crops (annual), irrigated	Croplands; cropland/natural vegetation mosaic
Barren land	Bare areas	Barren or sparsely vegetated

Table 2 User-defined classes and associated classification code of LULC products.

LULC products	Classification system	User-defined land use land cover classes				
		Trees (1)	Grassland (herbaceous) (2)	Shrubland (3)	Cropland (4)	Barren land (5)
MODIS	IGBP-GVCS	2, 4, 5 ^a	10, 11	6, 7, 9, 8	12, 14	16
GLC 2000	UN-LCCS	3, 4, 7, 10	13, 14, 15	11	18	19
GlobCover V2.2 and 2.3	UN-LCCS	40, 60, 110	120, 140	30, 130, 150	14, 20	200
RCMRD and EMA	IPCC Scheme II	2, 7, 11, 12	8, 10, 13	16, 18	3, 4	5, 9, 17
GlobeLand30	Combined	20	30, 60	40	10	90
GLCNMO	UN-LCCS	1, 2, 3	8, 9	7	13	17
GLC-SHARE	UN-LCCS	4	3, 6	5	2	9
ALCM	—	3, 4	—	2	—	5, 6, 7
CCILCA	Combined	1	3, 5	2	4	—

^aLand cover class code based on the classification system used in each LULC product. The code descriptions are available as Video 1 (classification codes' description) (Video 1, MP4, 12.4 MB [URL: <https://doi.org/10.1117/1.JARS.12.041502.1>]).

Table 3 Land use land cover products for Ethiopia between the years 2000 and 2018.

Product name	Code	Satellite image	Spatial res. of satellite image	Product spatial res.	Geospatial data type	Classification system	No. of classes	Overall accuracy (%)	Year	Source
MODIS	M	MODIS	500 m	500 m	HDF-EOS	International Geosphere Biosphere program-global vegetation classification scheme (IGBP-GVCS)	17	75	2001 to 2013 (annually)	NASA
GLC 2000	G1	SPOT vegetation sensor	1 km	1 km	Grid	UN-LCCS	22	68.60	2000	FAO
GlobCover V2.2 and 2.3	G2	MERIS	300 m	300 m	GeoTiff	UN-LCCS	22	67.5 (V2.2) and 73 (V2.3)	2005 and 2009	ESA
RCMRD and EMA	R	Landsat	30 m	30 m	GeoTiff	Intergovernmental Panel on Climate Change (IPCC) 6 land cover categories for scheme II	16	87.97 (2003), 86.68 (2008), No data for 2013	2003, 2008, and 2013	RCMRD and EMA
GlobeLand30	G3	Landsat, MODIS, HJ, FY-3	30 m	30 m	GeoTiff	The existing different land cover classification systems	10	80	2000 and 2010	Ref. 29
GLCNMO	G4	MODIS and Landsat	1 km (2003) and 500 m (2008 and 2013)	1 km (2003) and 500 m (2008 and 2013)	GeoTiff	UN-LCCS	20	76.50	2003, 2008, and 2013	Refs. 31 and 32
GLC-SHARE	G5	Aggregate of LULC maps		1 km	GeoTiff	UN-LCCS	11	80.20	2014	
ALCM	A	Landsat	30 m	500 m	Raster-GeoTiff	—	7	88	2000 to 2015 (annually)	Ref. 1
CCILCA	S	Sentinel 2	10/20 m	20 m	GeoTiff	Existing legends used within global land cover databases	15	82.8	2016	ESA

The GLCNMO is a 1-km global land cover product based on 16-day MODIS observation composites from 2003.^{31,32} It also uses the aforementioned UN-LCCS classification system. Supervised and independent classification methods were used to derive 14 and 6 (urban, open tree, mangrove, wetland, snow/ice, and water) classes, respectively. The Global Land Cover SHARE (GLC-SHARE) product is a beta release from 2014 by the UN FAO.³³ The project's objective is to derive the best available global land cover map from different global, regional, and national scale databases such as GlobCover 2009 and MODIS vegetation continuous fields.

The African land use land cover map product by Midekisa et al.¹ provides annual (2000 to 2015) land cover information produced on the continental scale for Africa. It uses day- and night-time lights satellite observations from Landsat 7 ETM+³⁴ and operational linescan system flown on Defense Meteorological Satellite Program satellites.³⁵ The CCILCA product is a prototype product of Africa 2016 and uses a 1-year (from December 2015 to December 2016) Copernicus Sentinel-2A Earth observation imagery to provide a 20-m spatial resolution.^{36,37} It is produced by CCILC project as part of the ESA CCI project using the random forest and machine learning classification algorithms.

2.3 Ground Truth Data for Bale Mountains National Park

To evaluate the aforementioned national to global scale LULC products, ground truth data were collected throughout the BMNP in 2016 (Fig. 2). The data are grouped into the major LULC classes that are present in the study region (trees, shrubland, herbaceous grassland, cropland, and barren land, see Table 1). Google Earth imagery from 2013 was cross referenced to ensure that the ground truth sites have not changed since 2013 and can be compared with the following LULC products: MODIS IGBP-2013, RCMRD and EMA-2013, GLCNMO-2013, GLC-SHARE-2014, ALCM-2015, and CCILCA-2016. The respective LULC product classes were reclassified into the classes of the ground truth information according to Table 2.

3 Results and Discussion

3.1 Available LULC Products in Ethiopia (National to Global Scale)

Table 3 shows the nine LULC products available from 2000 to 2018 at the global or national scale in terms of satellite image used, spatial resolution, geospatial data type, classification system, number of classes, overall accuracy, year, and source. These LULC products have 20-, 30-, 300-, 500-, and 1000-m spatial resolutions. Overall, the classification accuracy of

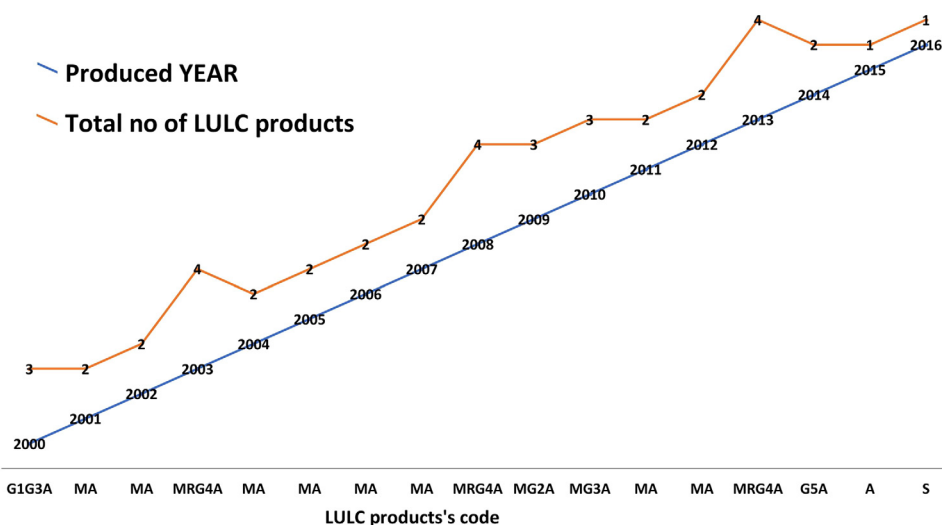


Fig. 3 Number of LULC products identified from national and global scale between 2000 and 2018 (product codes from Table 3).

these products ranges from 67.5% (GlobCover-2005) to 88% (ALCM). Altogether the nine LULC products provide 41 time slices with the highest number of products (four) available for 2003, 2008, and 2013 (see Fig. 3). Figures 4 and 5 show the CCILCA 2016 and GLC-SHARE 2014 with 20-m and 1-km spatial resolutions, respectively.

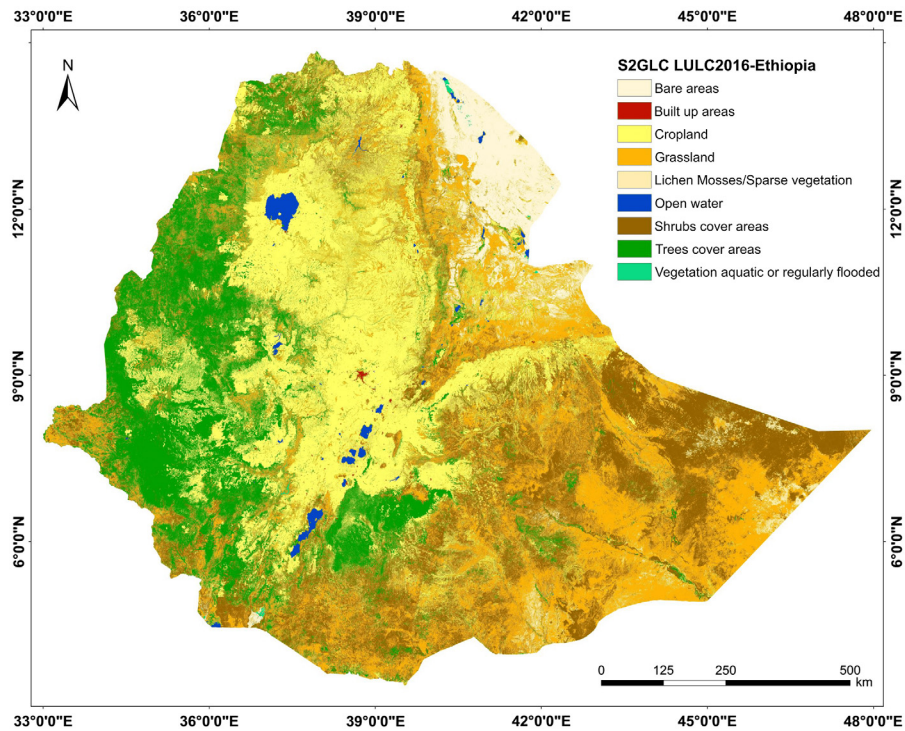


Fig. 4 The CCILCA (2016) LULC product for Ethiopia with 20-m spatial resolution.

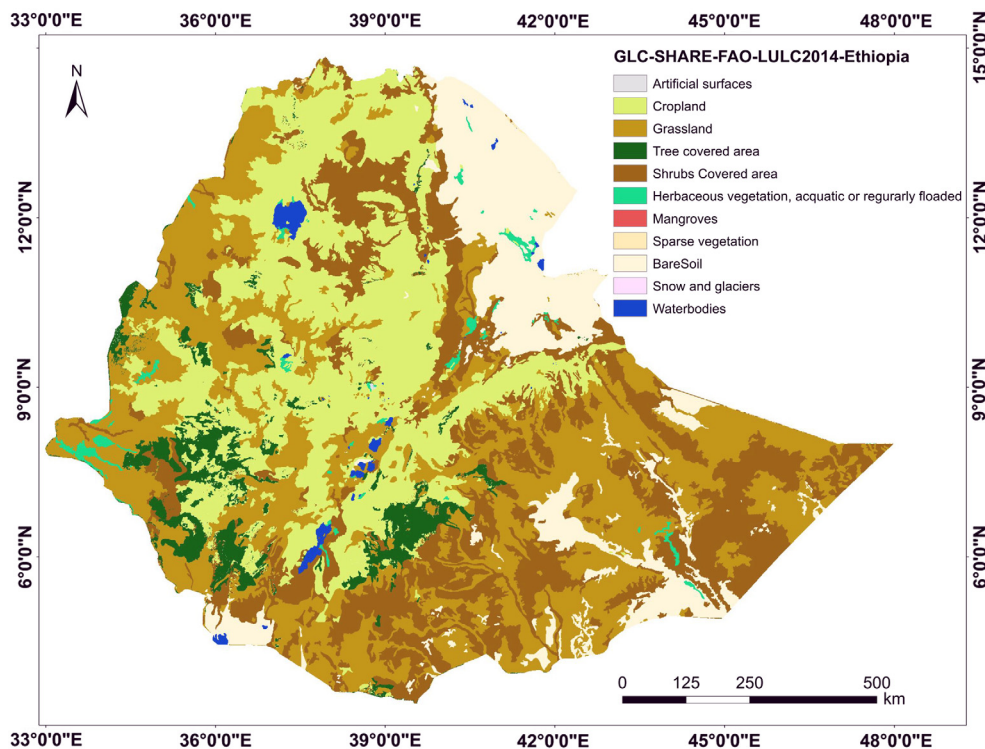


Fig. 5 The GLC-SHARE (2014) LULC product of Ethiopia with 1-km spatial resolution.

3.2 Systematic Literature Review

The 146 publications were synthesized based on study area, elevation, use of satellite images, LULC products, publication year, and accuracy assessment result. In general, the number of publications per year increased until 2017 [see Figs. 6(c)] reaching a maximum of 26 in 2017. This signifies the importance of LULC information for Ethiopia within the scientific community. LULC analyses were completed throughout Ethiopia with most of the studies (73) completed in the northern part of Ethiopia, in the Tigray and Amhara regions [Fig. 6(a)]. The second most studied area (39 publications) is the central region, which includes the Ethiopian Rift Valley. In terms of elevation, 140 studies were conducted in an altitude range above 1500 m a.s.l. and only six in areas below 1500 m a.s.l.

In the publications, LULC was mapped using satellite images [Fig. 6(b)]. Landsat was the most popular satellite, used in 126 papers, whereas SPOT was used in 10 studies and

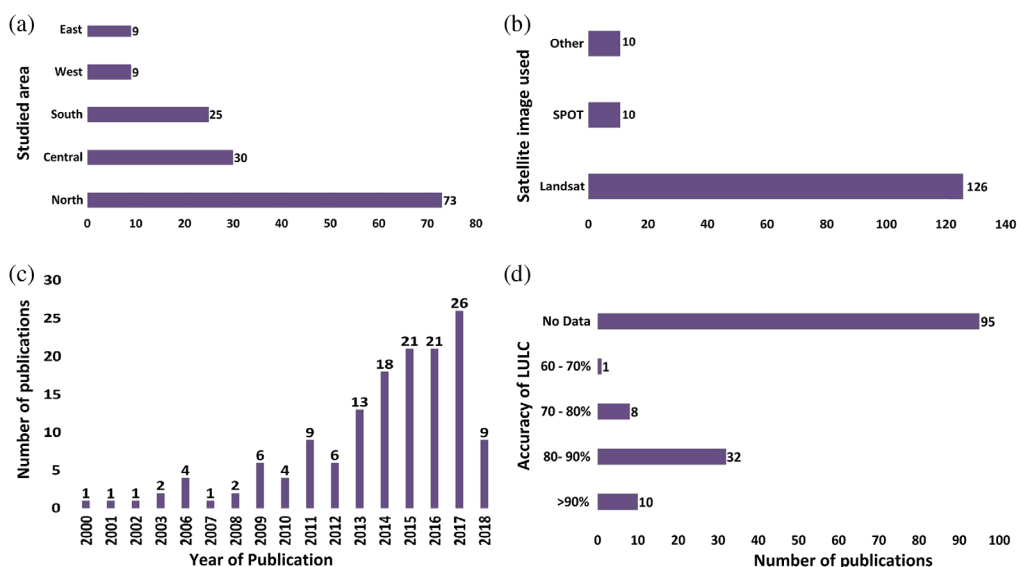


Fig. 6 (a) Number of publications in terms of their location, (b) satellite image used, (c) year of publication, and (d) accuracy of LULC they produced.

Table 4 Producer and user accuracy of the LULC products. The highest producer accuracy values for each Land Cover class represented as bold.

LULC product		Tree cover	Grassland (herbaceous)	Shrubland	Cropland	Barren land	Overall accuracy (%)
CCILCA	PA	73.8	32.5	77.8	22.2	NaN ^a	49.19
	UA	96.9	68.4	34.6	37.5	0.0	
ALCM	PA	70.5	NaN	60.0	NaN	21.1	47.57
	UA	96.9	0.0	51.9	0.0	83.3	
MODIS	PA	79.5	26.3	36.4	55.6	NaN	41.77,
	UA	100.0	74.3	6.6	38.5	0.0	
GLC-SHARE	PA	40.5	33.7	NaN	0.0	0.0	33.51
	UA	100.0	78.9	0.0	0.0	0.0	
RCMRD/EMA	PA	29.7	0.0	87.5	1.4	0.0	20.54,
	UA	93.8	0.0	8.6	6.2	0.0	
GLCNMO	PA	34.0	6.2	15.4	NaN	NaN	20.54
	UA	100.0	5.3	4.9	0.0	0.0	

^aThere is no LULC class in the product within BMNP. PA, producer accuracy and UA, user accuracy.

10 publications used other data sources, such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (2), aerial photographs (2), and QuickBird (1). Three publications studied LULC change analysis using community participation by questionnaires and interviews without using satellite images, whereas two other publications used field observation LULC data. In terms of accuracy, more than 90%, 80% to 90%, 70% to 80%, and 60% to 70% accuracy was reported in 10, 32, 8, and 1 publication, respectively [Fig. 6(d)]. In 95 research papers, the accuracy of the classifications was not mentioned. The results in Fig. 6(b) show that most researchers prefer to create an LULC map by analyzing freely

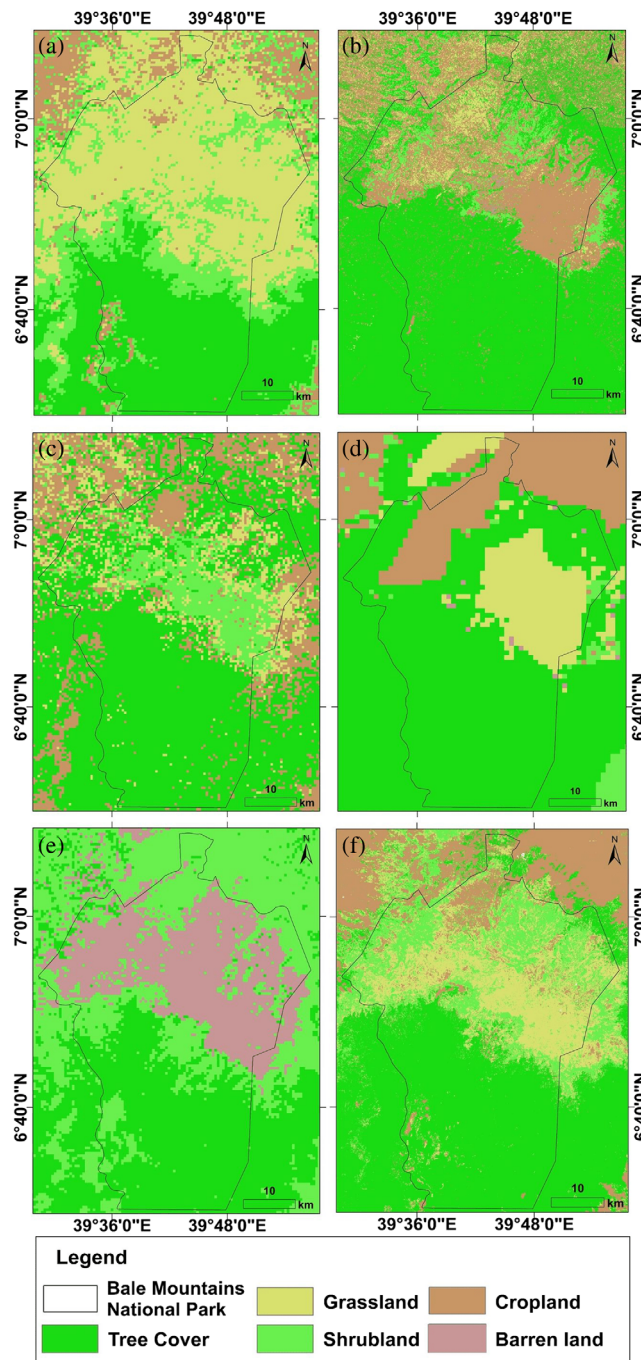


Fig. 7 Maps of LULC products for BMNP: (a) MODIS IGBP-2013 (500 m), (b) RCMRD and EMA-2013 (30 m), (c) GLCNMO-2013 (500 m), (d) GLC-SHARE-2014 (1 km), (e) ALCM-2015 (500 m), and (f) CCILCA-2016 (20 m).

available satellite images like Landsat instead of using one of the available LULC products introduced in Sec. 3.1.

Of the 146 publications, 36 were from peer-reviewed journals with environmental themes such as *Science of the Total Environment*;^{38–41} *Agriculture, Ecosystems, and Environment*;^{42–44} *Environmental Monitoring and Assessment*;^{7,42,45–47} *Environmental Systems Research*;^{48–50} *International Journal of Environmental Studies*,^{40,51,52} and *Journal of Environment and Earth Science*.^{53–55}

The LULC maps are used in a variety of application areas. These include watershed management (40), hydrology (31), lowland management (21), highland management (20), urban studies (12), social studies (12), forest management (6), and agriculture (4). This implies that authors find the LULC analysis quite important for water-related applications such as watershed management or surface and groundwater hydrology in Ethiopian river basins like the Upper Blue Nile, Tekeze, Awash, Baro, Ghibe, and Rift Valley Lakes basins. Most studies were done in Upper Blue Nile River basin,^{38,41,44,46,48,56–63} followed by studies in the Central and Rift Valley Lakes basin.^{64–68}

3.3 Evaluation of LULC Products in the High-Altitude Area of the Bale Mountains National Park (National to Global Scale)

Given most of the reviewed studies focus on mid- to high-altitude regions, we evaluated the accuracy of six of the available national to global scale LULC products in the BMNP area, which ranges between 1500 and 4385 m a.s.l (see Table 4, Fig. 7). Regarding the overall accuracy of these products, the CCILCA-2016 (49.19%), ALCM-2015 (47.57%), MODIS-2013 (41.77%), GLC-SHARE-2014 (33.51%), RCMRD/EMA-2013 (20.54%), and GLCNMO-2013 (20.54%) all have <50% overall accuracy. The most accurate product for high-altitude areas—the 20-m CCILCA-2016—correctly explains the LULC classes with 49.19% overall accuracy, which may indicate why they are infrequently utilized in the reviewed studies.

The producer accuracy (Table 4) reveals that tree cover (79.5%) and cropland (55.6%) is best explained by the MODIS product. Grassland (33.7%), shrubland (87.5%), and barren soil (21.1%) are best predicted by RCMRD/EMA, CCILCA, and ALCM, respectively. However, RCMRD/EMA shows 0% accuracy for grassland and barren soil. The same is true for GLC-SHARE but for cropland and barren soil. Tree cover shows the highest value of user accuracy in all LULC products. That is, all land cover products are accurate in terms of classifying the tree cover class.

4 Conclusions

The review of 146 LULC studies in Ethiopia revealed that in addition to the availability of national to global scale LULC products, most researchers (83%) prefer to create an LULC using satellite images like Landsat. About 73% of the studies have been published since 2013 and no study since then has used an available LULC. This might be related to the rather poor overall accuracy (<50%) of the available products, especially in high-elevation areas, where most studies have their focus. The reviewed LULC products may be usable at regional and national scale because the classification accuracy ranges from 67.5% to 88% as shown in Table 3 and further studies recommended on the accuracy taking the scale into consideration.

Acknowledgments

This work was supported by Deutsche Forschungsgemeinschaft (DFG) Award no. NA 783/12-1, AOBJ 628803 through a project entitled “The mountain exile hypothesis: how humans benefited from and re-shaped African high-altitude ecosystems during Quaternary climatic changes” within the framework of the Research Unit 2358. The authors acknowledge ESA CCI Land Cover project for making CCILCA available. Dr. Binyam Tesfaw Hailu is currently a Georg Forster post-doctoral Fellow with the Alexander von Humboldt Foundation.

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